Geophysical investigation into the integrity of a reclaimed open dumpsite for civil engineering purpose

Theophilus Aanuoluwa Adagunodo [a], Adetunji Ayokunnu Adeniji [b], Ayobami Victor Erinle [c], Sayo Akinloye Akinwumi [a], Olusegun Oladotun Adewoyin [a], Emmanuel Sunday Joel [a], Olusola Titilope Kayode [a]

[a] Department of Physics, Covenant University, Ota, Ogun State, Nigeria
[b] Department of Physics and Solar Energy, Bowen University, Iwo, Osun State
[c] Department of Pure and Applied Physics, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria
taadagunodo@yahoo.com; taadagunodo@gmail.com; theophilus.adagunodo@covenantuniversity.edu.ng

Abstract

Structural failure is one of the concerns of earth scientists in the in the recent time. Most of the building engineers neglect investigation into the subsurface structure prior to construction without taking into cognizance the soil type and its variation which is one of the contributing factors to frequent building collapse in this era. Integrated geophysical methods involving ground magnetic, Very Low Frequency-Electromagnetic (VLF-EM) and Vertical Electrical Sounding (VES) were adopted with a view to investigating into the integrity of a reclaimed open dumpsite in Oyo for civil engineering worthiness. Three (3) traverses were occupied for ground magnetic and VLF-EM survey. A total length of 100 m was occupied in each traverse along E-W orientation with inter-station spacing of 10 m. Six (6) VES stations were occupied along two geoelectric profiles in the study area. The ground magnetic study showed magnetic highs and lows both on the profiles and the generated 2-D map. The magnetic highs are competent zones for civil engineering construction while magnetic lows are incompetent zones. The VLF result revealed conductive and non-conductive zones. More than half of the area of study is characterized with conductive signatures. Conductive zones are regarded as the incompetent zones while the non-conductive zones are regarded as competent zones. The VES result showed that the five out of six VES points occupied are underlain with fractured bedrock while only VES 3 showed fresh bedrock. It is concluded that the study area unsuitable for the construction of giant structures.

Keywords: Subsurface integrity, Civil engineering purpose, Reclaimed open dumpsite, Ground magnetic, Very low frequency – electromagnetic, Electrical resistivity

Introduction

Lack of relevant technique(s) to probe into subsurface for its integrity is one of the factors that are responsible for persistent structural failure in our society. Unceasing occurrence of building collapses has facilitated this research. A reclaimed dumpsite is known to contain decomposed body that has form additional strata to the overburden of the subsurface. In the assessment of a reclaimed open dumpsite, a lot might be at stake in what the area is being planned to be used for considering the long time effects of waste dumping might have on soil engineering. A reclaimed dumpsite could be dangerous in the sense that the sediments in the terrain might have led to thick

overburden which could be disastrous for high-rise building if not investigated properly using geophysical techniques before the construction of buildings commence. In another words, bulldozing of dumpsite for civil engineering purpose without a geophysical study to investigate into the competency of such land is a risk as the supporting soil formation might be unable to withstand the structure(s) intended to be built on it.
The safety of life and property is utmost importance when formulating any policy or developing any project. When a natural phenomenon occurs which often is beyond the control of man, it is wise that the root of such incidence be investigated and preventive measures proffered to either stem future occurrence or to put those in the area on alert. Adagunodo et al. (2014) reported some cases of building failures in some parts of Nigeria from year 1976 to 2014. Recurring nature of building collapse in Oyo state, Nigeria has necessitated this study. According to Walter (2015), six reasons for building collapse include: soil type, use of low quality building materials, use of incompetent craftsmen leading to poor workmanship, weak supervision, poor building design and planning, and natural disaster. The purpose of this work is to investigate the thick overburden that might have arisen from the dumping of refuse and the nature of bedrock formation in the study area which could be disastrous for building construction.
Powrie et al. (2015) posited that construction on or across closed municipal solid waste landfill sites will attract a special set of geohazards associated with the potential for large and difficult to predict settlements. Adewoyin et al. (2017) also reported that the chanllenges of geotechnical investigation for pre-foundational civil engineering study have made many private developers carry out various construction projects without undertaking a proper site investigation. Some critical reviews about application of geophysical engineering purposes have been presented by Ozcep and Ozcep (2011).
Geophysical techniques used for this study include ground magnetic, Very Low Frequency Electromagnetic (VLF-EM), and Electrical Resistivity (ER) involving Schlumberger array. The magnetic method involved investigating subsurface geology on the basis of anomalies in the earth’s magnetic field resulting from the magnetic properties to the underlying rocks. The technique requires measurements of the amplitude of magnetic components at discrete points along traverses distributed regularly throughout the survey area of interest (Parasnis, 1978; Okwueze, 2000; Kearey et al., 2004). Very low Frequency Electromagnetic Method (VLF-EM) is a geophysical ground probing techniques that utilizes Very Low Frequency signals (in the range of 10–30 kHz) normally used for submarine and military communication. VLF-EM method relies on transmitted currents inducing secondary responses in conductive geologic units (Gnaneshwar et al., 2011). Electrical resistivity method of geophysics is based on electrolytic conduction, where current and potential electrodes are coupled to the ground and connected to resistivity metre through conducting wires. The rule of thumb is that the farther apart the current electrodes, the deeper the depth of penetration (Dobrin, 1976). The principles of operation of ground magnetic, VLF-EM, and ER techniques have been discussed extensively by Adagunodo et al. (2015), Oladejo et al. (2013; 2015), and Adagunodo et al. (2013) respectively. These techniques have found applications in civil engineering in recent times (Sunmonu et al ., 2012; Adagunodo et al., 2013; Oladejo et al., 2013; 2015; Adagunodo et al., 2014; Adagunodo et al., 2015a; Adagunodo et al., 2015b; Sunmonu et al., 2016; Raji and Adeoye, 2017).

The Study Area and its Geology

The Oyo Empire was a Yoruba Empire of what is today's western and northern Nigeria. Established in the 14th century, the Oyo Empire grew to become one of the largest West African states. It rose through the outstanding organizational skills of the Yoruba, wealth gained from trade and its powerful cavalry. After the departure of the colonial masters, the country was split into states (Fig.1) which now bring about the town of Oyo, Oyo state, Nigeria which is the study area. A greater percentage of the vegetation of the town is grass and woodland and much of the land is covered by fertile loamy soils which are derived mainly from the Precambrian hornblende biotite gneiss (Fig. 2).

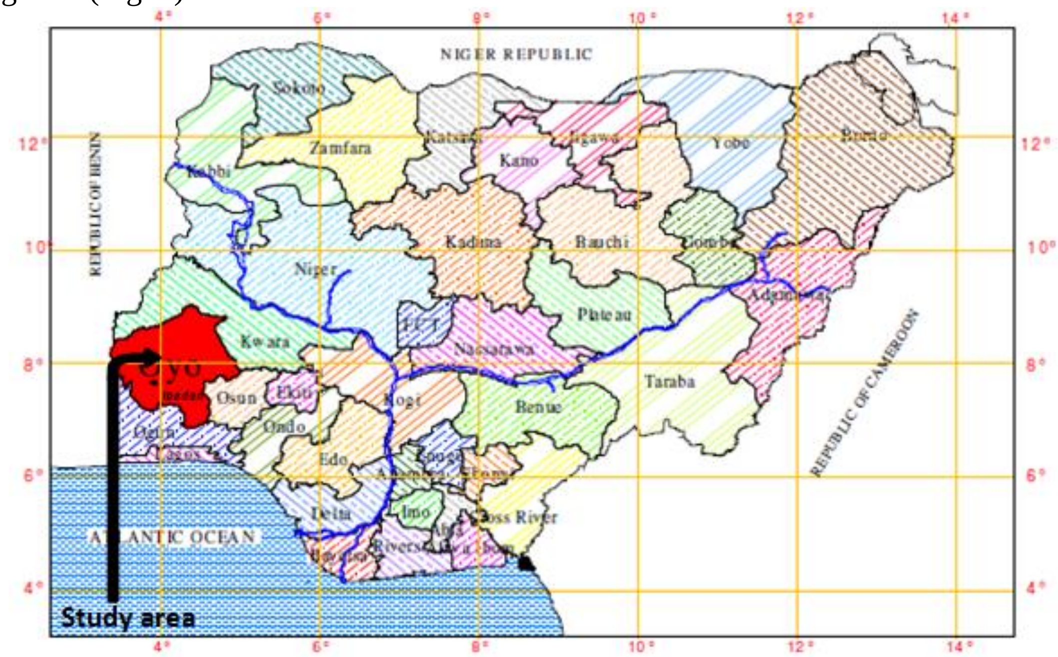

Fig. 1. Map of Nigeria showing the state of the study.

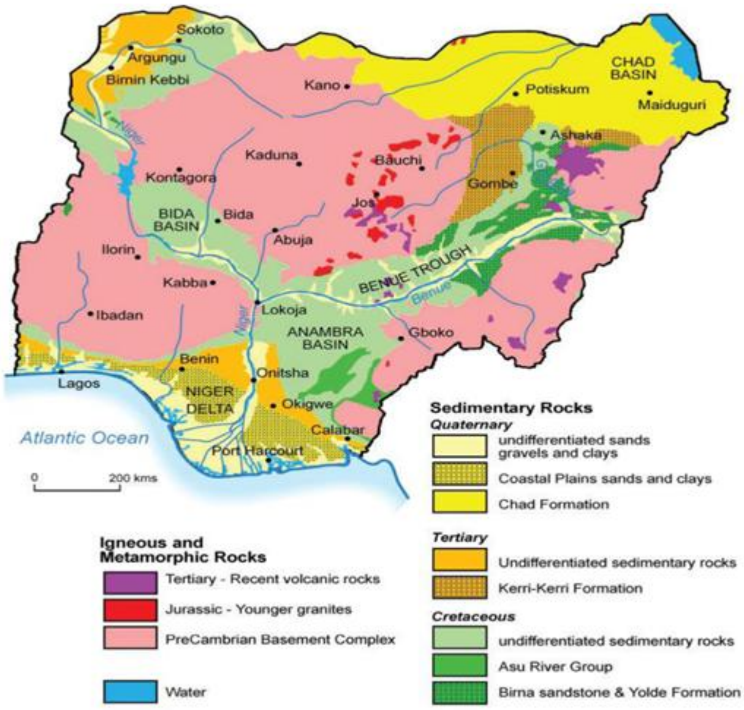

Fig. 2. Geological map of Nigeria

The studied area lies within the crystalline basement complex of Nigeria (MacDonalds, 2000). It lies within latitude $N\ 07^{\circ}51.100'$ to $N\ 07^{\circ}51.300'$ and longitude $E\ 003^{\circ}55.500'$ to $E\ 003^{\circ}55.944'$. The landscape consists old hard rocks and dome shaped hills which rise gently across the town. The area is covered by Precambrian igneous and metamorphic rocks which extend over the state and larger quantities of quartzites are found inset too. It is not particularly rich in prominent materials but endowed with a wide distribution sedimentary and metamorphic group of minerals, namely: Marble, Red clay, Sand, Gravel, Granite, Limestone and Talc. The climate is equatorial, notably with dry and wet seasons with relatively high humidity, the average daily temperature ranges between 25 ℃ and 35 ℃ across the year.

Materials and Methods

A geophysical survey was carried out using ground magnetic method where a total of three traverses were established. The maximum traverse length of 100 m with inter-spacing of 10 m was occupied. This method is slow but it yields a detailed pattern of the magnetic field anomaly. The proton precession magnetometer gives the total magnetic intensity reading (regional magnetic field and residual anomaly field) for each station. A base station was carefully selected, where magnetic intensities were being measured at a stationary point. This was done to keep track of diurnal variations and drift. The raw data was filtered in order to increase the signal-to-noise ratio of the data, the residual anomaly fields were further enhanced using total derivative gradient technique. The total derivative gradients were presented as magnetic profiles where depths to magnetic sources were obtained. 2-D contour map and 3-D map (surface plot) of the total derivative gradient were obtained using Surfer software version 11.

VLF-EM survey utilizes the magnetic component of the electromagnetic field (primary field generated by military radio transmitters that uses the frequency band (Very Low Frequency, 15-

ISSN: 0378-1844

30 kHZ). The primary field sent into the subsurface causes eddy current to flow in conductor at the subsurface which create magnetic (secondary) field. The VLF receiver measures the difference in direction and phase between the primary and secondary field. In order to create any secondary field, a body must have a minimum size and sufficiently low resistivity. Normally the strike length of the body must exceed about 50 m and the depth extent must exceed about 10 m for induction to occur. The WADI detects the ratio in (%) between the vertical and horizontal components. Because the primary field from the transmitter is horizontal, the normal reading on the WADI will be zero. Even in the presence of horizontal lying conducting layer, the reading will be zero. It is only in the case of steep conductors that any VLF anomaly will appear. The deviation from the normal readings are called anomaly. The VLF is useful for the detection of steeply dipping low resistivity bodies. The maximum traverse length of 100 m with inter station spacing of 10 m was also occupied for this method because the measurement was taken along the magnetic traverse lines. The In-phase component of the recorded data was employed for further processing.

A total of 6 Vertical Electrical Soundings (VES) stations were occupied randomly (Fig. 3) to cover the area of study. The Schlumberger array was used for the field resistance measurements. For each movement of current electrode positions the product of the resistance measured and the corresponding value of the geometric factor (G) gave the measured ground apparent resistivity. The VES curves were generated by applying the convectional curve matching (Zohdy and Maboy, 1974). The VES curves generated gives the thickness and the resistivity of different layers. A more reliable interpretation of field data using direct calculation with the aid of computer iterating software has been advanced in recent time. The results from the partial curve matching (on WinGlink software) (Sunmonu et al., 2016), that is, the layer resistivity and the corresponding depths to the various layers were used to generate theoretical VES curves by inputting into a computer iterative programme (Win Resist software). The depth sounding curves were then classified according to the resistivity contrasts between the layers as H, K, A, Q or multiples thereof, following the classification by Keller and Frischnecht (1970).

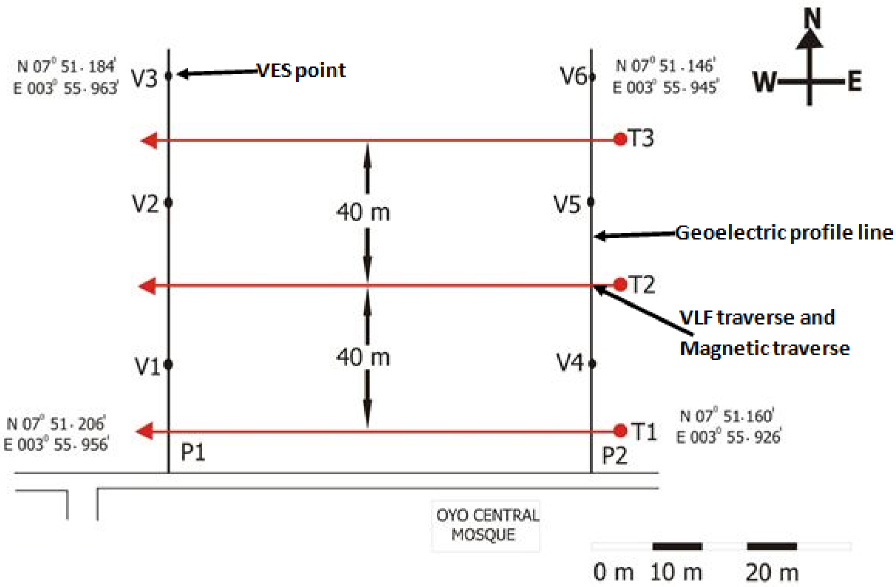

Fig. 3. Base map of the study area

Results and Discussion

Ground magnetic interpretation

The magnetic values were plotted and subjected to qualitative and quantitative interpretation. The former was made by visualizing the plotted magnetic profiles, the contour map and the surface plot. This is based on the fact that features are rather directly related to surface outcrops and a magnetic contour map may be fair substitute for surface geology map in areas where geological maps is unavailable. For instance, region dominated by Igneous and Metamorphic rock usually shows steep gradient and high relief in the magnetic contours. The quantitative interpretation was used to estimate depth to source of magnetic anomalies employing half-width of the amplitude method (Adagunodo and Sunmonu, 2013).

Traverse 1 covers a total length of 100 m (Fig. 4a) and trends in East to West direction. The traverse shows series of magnetic highs and lows. The magnetic highs are suspected to be due to near surface magnetic minerals such as crystalline rocks (Igneous or Metamorphic) and the areas are better for erecting both low and high-rise buildings because the subsurface appears to be competent enough to withstand heavy load that might be constructed on it. The magnetic lows at distance 30 m and 42 to 80 m are likely to be due to the presence of non-magnetic minerals such as fault, fracture, crack or contact between two rocks. These areas with magnetic lows may be dangerous for high-rise building if such building is constructed along the planar features' orientation.

Traverse 2 covers a total length of 100 m (Fig. 4b) and trends in East to West direction. The traverse shows areas with magnetic highs with prominent positive anomaly at 10 m. The sharp amplitude is suspected to be an outcrop. The magnetic highs are suspected to be due to near surface magnetic minerals such as crystalline rocks (Igneous or Metamorphic). It may also be due to intrusive igneous bodies concordantly intruding into the country rock (Migmatite-gneiss). These areas are capable to withstand the pressure of a high-rise building. Other areas that show magnetic lows cannot be outrightly condemned because they might not necessarily be fractured zones, the signatures might be due to thick overburden in the study area. This is the reason while other geophysical technique such as VES was integrated with ground magnetic method during the geophysical survey.

Traverse 3 covers a total length of 100m (Fig. 4c) and trends in East to West direction. The traverse shows areas with magnetic highs and lows. The magnetic highs is suspected to be an outcrop and suspected to be due to near surface magnetic minerals such as crystalline rocks (Igneous or Metamorphic) while the magnetic lows are described otherwise. The magnetic lows are an indicative of features like joints or rock contact. However, this traverse resembles other traverses in terms of signatures.

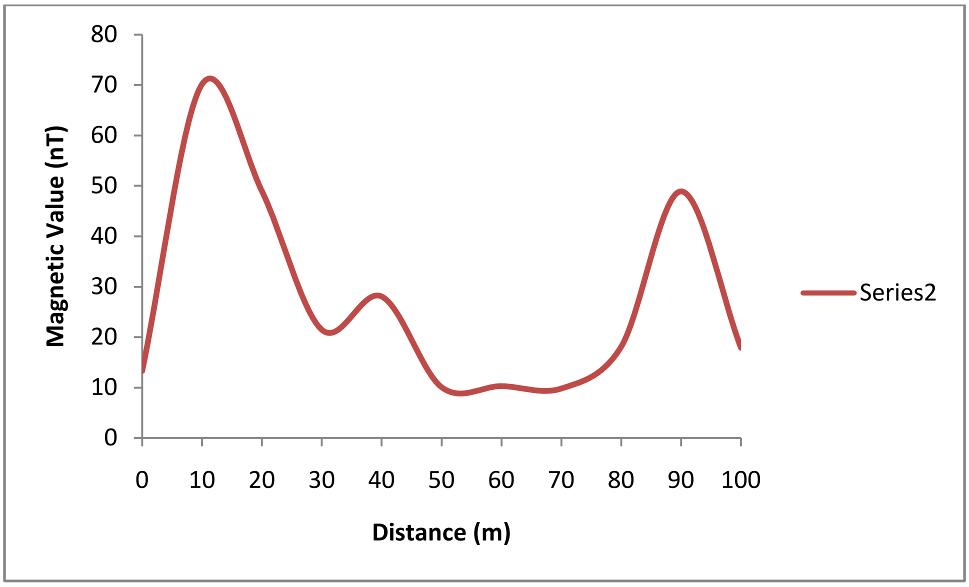

Fig. 4a. Magnetic profile along traverse 1

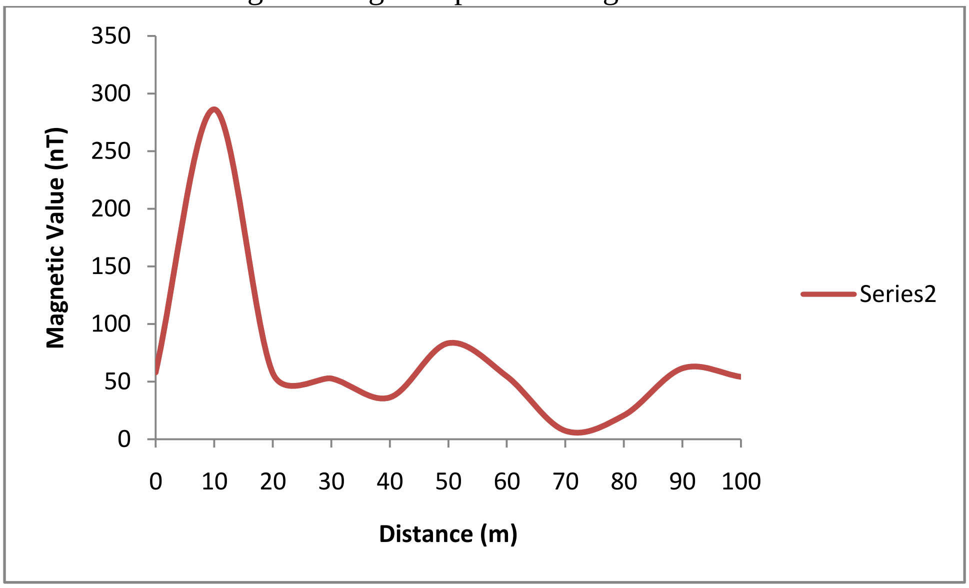

Fig. 4b. Magnetic profile along traverse 2

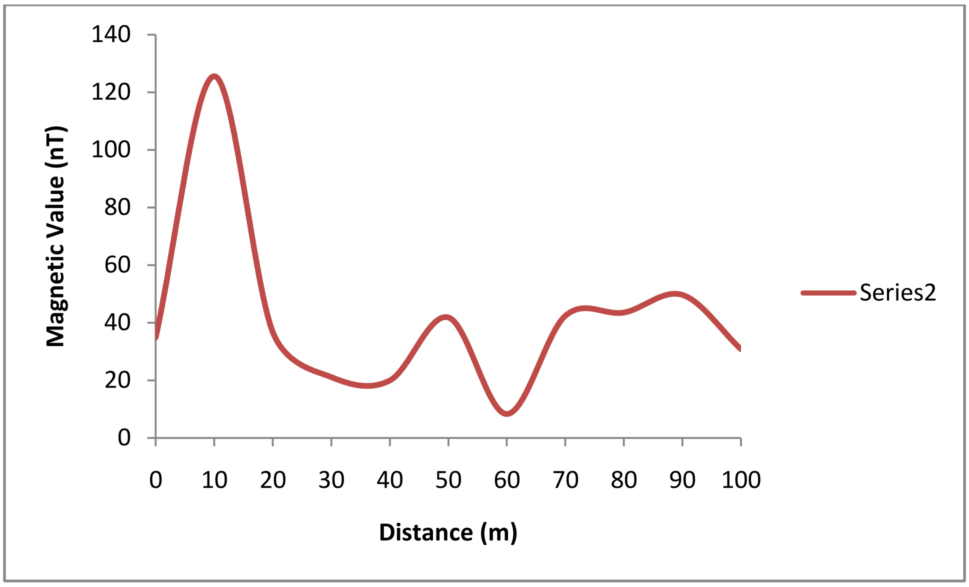

Fig. 4c. Magnetic profile along traverse 3

The magnetic 2-D contour map constructed using the magnetic values generated from enhanced filtering technique known as total derivative gradient is shown in Fig. 5. The contour map reveals the basement structure and show the structural trend in the study area. The magnetic susceptibilities of the study area are divided into three regions: low magnetic zone (magnetic values varying from -10 to 60 nT), average magnetic zone (magnetic values varying from 60 to 160nT) and high magnetic zone (magnetic values greater than 160 nT). The average magnetic zone is experienced towards the western flank of the study area, the central part which is extended to the eastern, Northeastern, and Southeastern part of the study area. High magnetic zone is vividly experienced at the eastern flank of the study area. However, low magnetic zone dominate the remaining part of the study area. This low magnetic zone might be due to thick overburden or linear features like faults, fracture or void in the subsurface. High-rise buildings would not be favourable on this low magnetic zone.

The areas with magnetic highs along the magnetic profiles (Fig. 4a to 4c) were analyzed qualitatively. The summary of these results indicated varied basement topography with overburden thickness varying from 5 to 13 m. The results are presented in Table 1.

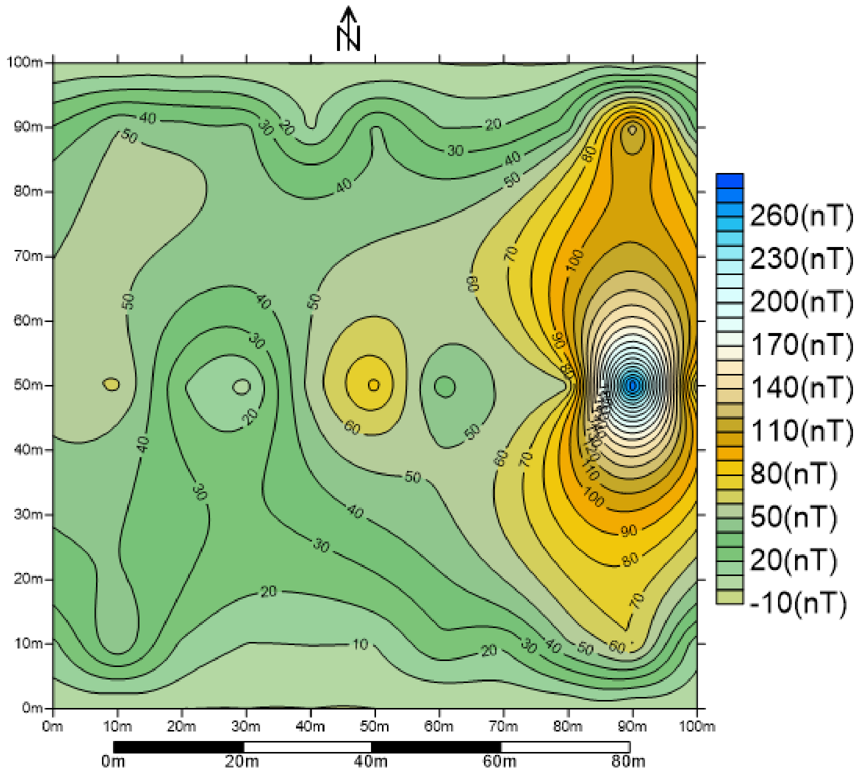

Fig. 5. Oke-Aremo 2D Magnetic contour map

Table 1. Summary of overburden thickness across each traverse

Traverses	Depth to Magnetic sources (m)		
	A	B	C
Traverse 1	8	4	5.5
Traverse 2	5.5	6.5	-
Traverse 3	6.5	5	13

VLF-EM filtering and qualitative interpretation

Anomalies of the raw in-phase data on a profile are usually not isolated, hence, tapering of the data prior to transformation is recommended. The VLF-EM technique is usually associated with large geologic noise component, which results from the relatively high transmitted frequency, long spatial wavelengths and direct current bias, thus, the data requires filtering in order to enhance the signals recorded. To make this VLF-EM field data easier to interpret and to smooth noisy data, the filtered real part is considered. This method has been employed by Oladejo et al. (2013). The contour 2D map and surface 3D map of the filtered real part was generated in order to explain the subsurface competency of the area. The negative signatures are the non-conductive zones while the positive signatures are the conductive zones. These conductive zones are interpreted to be underlain with linear geologic features.

The contour 2D (Fig. 6a) map is divided into conductive and non-conductive zones. The conductivities from -9 to 0 mho/m are classified as non-conductive zone while conductivity > 0

 ISSN: 0378-1844

mho/m is regarded as conductive zone. The colour code varied from black (non- conductive) to peach-pink (conductive) colour. The contour map showed that the study area is conductive. The Northern, Central, southern and the southeastern flank of the study area depict conductive zone which is underlain with linear geologic features while Northwestern, Western, Southwestern, Northeastern and the Eastern part of the study depict non-conductive signatures. The conductive zones are however regarded as incompetent zones while non-conductive zones are regarded as competent zones. The 3D map (Fig. 6b) was also generated from the in-phase component of the VLF data. The competent zones are classified with depression on the map.

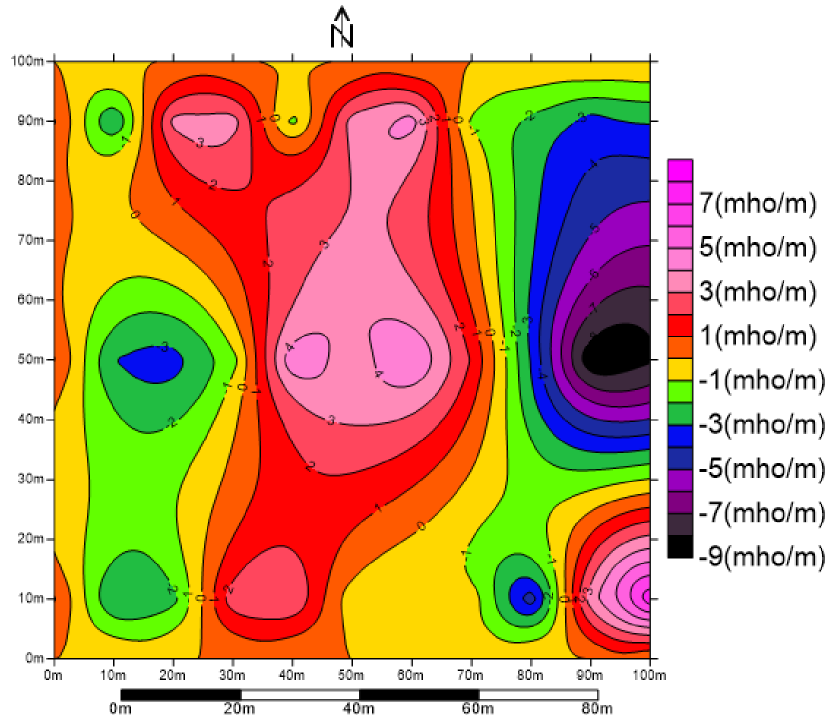

Fig. 6a. Contour (2D) map of VLF-EM data in the study area

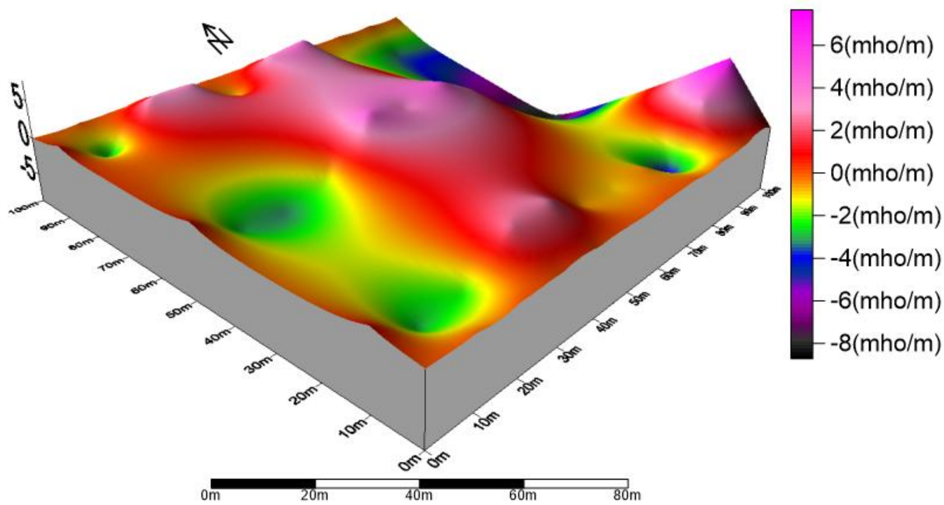

Fig. 6b. Surface (3D) map of VLF-EM data in the study area.

ISSN: 0378-1844

VES interpretation

The VES results are presented as the VES curves (Fig. 7a to 7f) and geoelectric sections (Fig. 8a and 8b). The VES curves were modeled from the computer and made sure that the RMS-error is as low as possible. It was observed that four VES stations showed three earth-layer model (VES 2, VES 4, VES 5, and VES 6) while the remaining two (VES 1 and VES 3) showed four earth-layer model. The overburden thickness of the study area varied from 1.1 to 8.5 m which showed that the study area is underlain with thin overburden. However, VES 1, 2, 4, 5 and 6 showed fractured basement while only VES 3 showed fresh basement. The classification of the sounding curves showed that VES 1 is the only HK- curve type, VES 2, VES 4 and VES 6 showed H-curve type, VES 3 showed QH-curve type while VES 5 showed A-curve type in the study area. The electrical resistivity results further confirms the magnetic result that the study area is unsuitable for the erection of high-rise building because of the linear features (fractured bedrock) present in the study area.

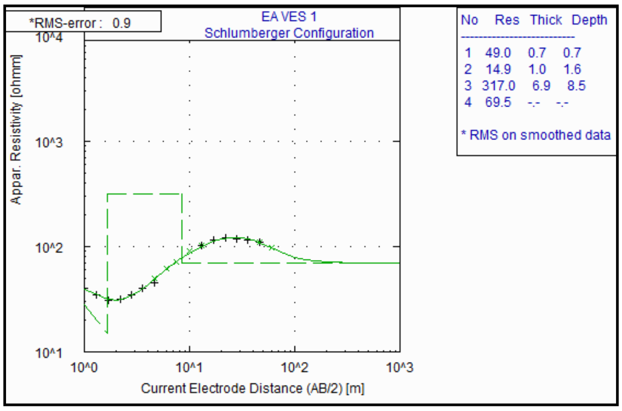

Fig. 7a. Modeled curve of VES 1

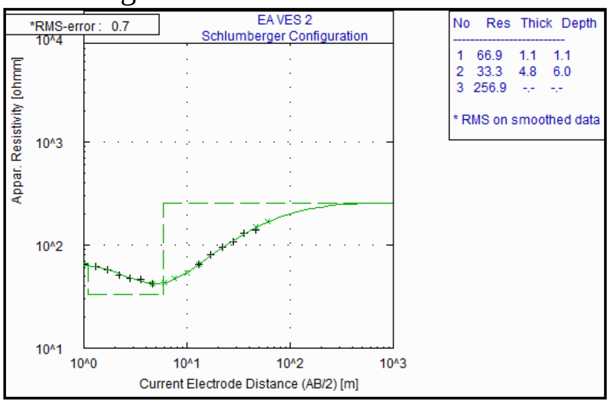

Fig. 7b. Modeled curve of VES 2

 ISSN: 0378-1844

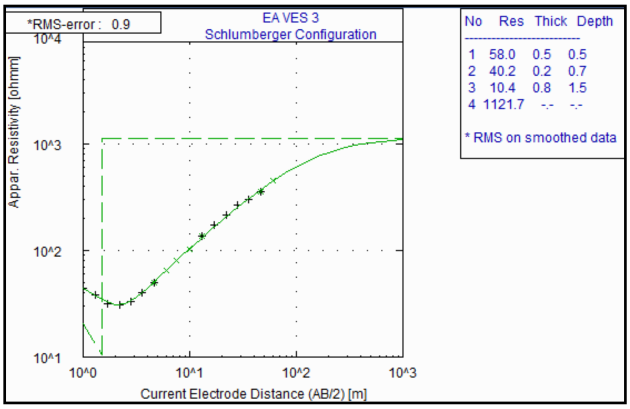

Fig. 7c. Modeled curve of VES 3

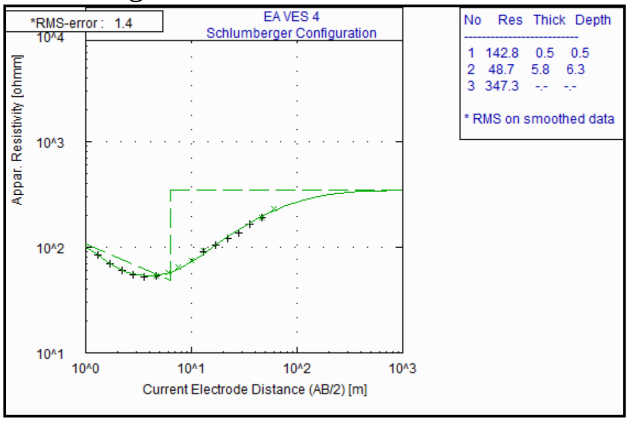

Fig. 7d. Modeled curve of VES 4

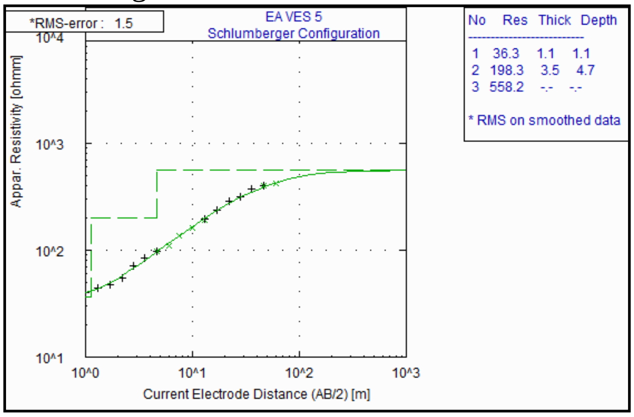

Fig. 7e: Modeled curve of VES 5

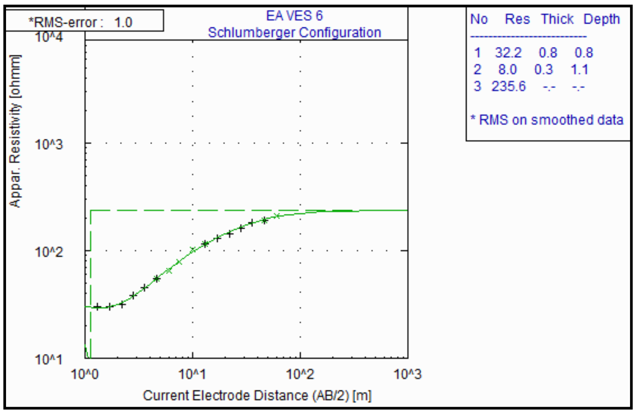

Fig. 7f. Modeled curve of VES 6

The six VES stations were grouped into two profiles (A and B) according to how convenient they can be located on a straight line to see image representation of the subsurface. The result of the interpreted VES curves were used to draw 2D geoelectric sections (Fig. 8a and 8b) along profiles A and B to show the vertical distribution of subsurface resistivity within the volume of the earth in the investigated area. The section consists sequence of uniform horizontal (or slightly inclined) layers (horizons). Each layer (horizons) in a geo-electrical section may completely be characterized by its thickness and true resistivity.

Geoelectric sections of profile A showed that the area is divided into 4 regions (Fig. 8a). The first, second and third region showed low resistivity (high conductivity) values with thin overburden thickness which confirms the ground magnetic results. The fourth region in VES 3 showed that the basement is fresh while that of VES 1 and VES 2 showed fractured basement / bedrock. This has proved that only northwestern flank of the study area is competent while other area is incompetent for civil engineering purposes. Geoelectric section of profile B shows that it is divided into 3 regions (Fig. 8b). The first and second region showed pocket of low resistivity values within this saprolitic zone. The third region revealed that the bedrock is fractured. This confirms that profile B is incompetent for civil engineering purposes.

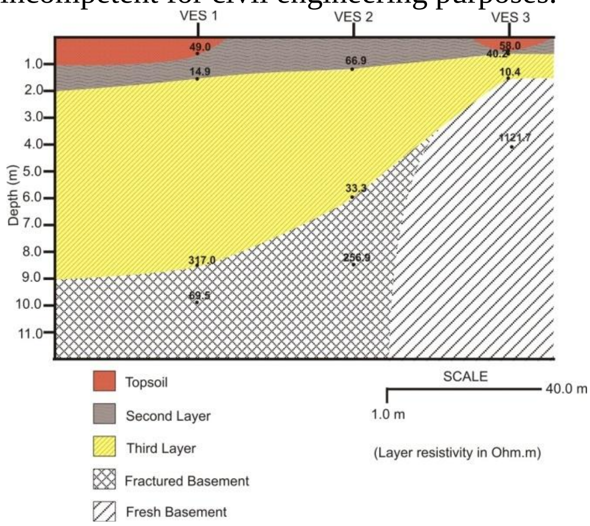

Fig. 8a. Geoelectric section along profile A

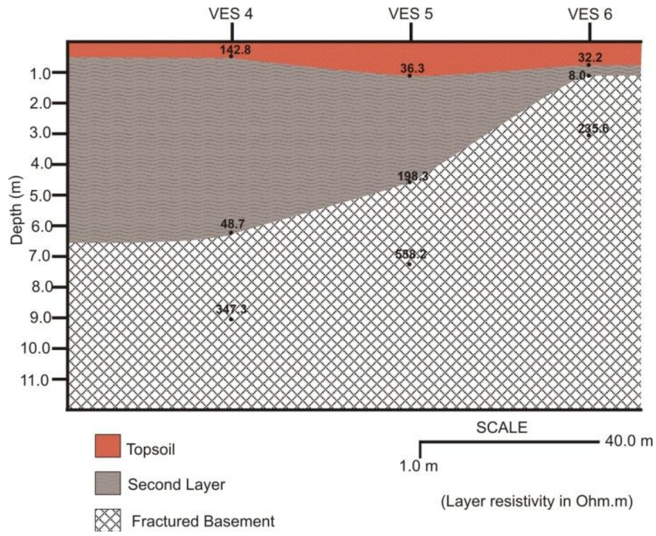

Fig. 8b. Geoelectric section along profile B

Conclusion and Recommendation

The study has been able to highlight the importance of geophysical methods in the stratigraphy study especially in the basement terrain. The study has affirmed that the competency of the study area is unsuitable for construction of giant structures. From the integrated geophysical approach employed in this study, groundwater exploration seems to be favourable there since the study area is intended to be used for construction of high-rise commercial centre. Groundwater exploration in crystalline bedrock is only favourable in areas with thick overburden and fractured basement.

Acknowledgement

The authors appreciate the partial sponsorship received from Covenant University, Ota, Ogun State, Nigeria.

References

Adagunodo Aanuoluwa and Sunmonu Ayobami (2013). The study of Basement Pattern of an Industrial Estate. LAP Lambert Academic Publishing, Germany, ISBN: 978-3-659-35930-9. https://www.lap-publishing.com

Adagunodo T.A., Sunmonu L.A. and Adabanija M.A. (2015a). Geomagnetic Signature Pattern of Industrial Layout Orile Igbon. *Advances in Architecture, City and Environment*. 1(3), 14–25.

Adagunodo T.A., Sunmonu L.A. and Adeniji A.A. (2015b). Effect of Dynamic Pattern of the Saprolitic Zone and its Basement on Building Stability: a Case Study of a High-Rise Building in Ogbomoso. *Journal of Applied Physical Science International*, 3(3), 106–115.

Adagunodo T.A., Sunmonu L.A. and Oladejo O.P. (2014). Effect of Constructing High-Rise Buildings without a Geophysical Survey. *Nigerian Journal of Physics*. Special Edition September 2014, 91–100.

Adagunodo T.A., Sunmonu L.A. and Oladejo O.P. (2014). Effect of Constructing High-Rise Buildings without a Geophysical Survey. *Nigerian Journal of Physics*. Special Edition September 2014, 91–100.

Adagunodo T.A., Sunmonu L.A., Ojoawo A., Oladejo O.P. and Olafisoye E.R. (2013), The Hydro Geophysical Investigation of Oyo State Industrial Estate Ogbomosho, Southwestern Nigeria Using Vertical Electrical Soundings. *Research Journal of Applied Sciences, Engineering and Technology*, 5(5), 1816–1829.

Adewoyin O.O., Joshua E.O., Akinwumi I.I., Omeje M. and Joel E.S., *Evaluation of Geotechnical parameters using geophysical data*, J. Eng. Technol. Sci. 49(1), pp. 95 – 113, 2017.

Dobrin M.B. (1976). Introduction to Geophysical Prospecting. McGraw-Hill Company, New York.

Graneshwar P., Shivaji A., Srinivas Y., Jettaiah P. and Sundararajan N. (2011). Very-Low-Frequency electromagnetic (VLF-EM) measurements in the Schirmacheroasen area, East Antarctica. Polar Science, 5, 11-19.

Karous M. and Hjelt S.E. (1983). Linear Filtering of VLF dip-angle measurements. Geophys. Prospect. 31, 782-792.

Kearey P. Brooks M. and Hill I. (2004). An Introduction to Geophysical Exploration. Third Edition, *Blackwell Pub*.

Keller S. and Frischnecht N. (1970). An interactive computer/graphic-display-terminal system for interpretation of resistivity soundings. Geophysics Prospect. 23, 449-458.

MacDonald A.M. and Davies J. (2000).A brief review of groundwater for rural water supply in Sub-Saharan Africa. B.G.S. Technical Report. W.C./00/33.

Okwueze E. (2000). Shell Intensive Training Program, *Geophysics Lectures*.

Oladejo O.P., Sunmonu L.A. and Adagunodo T.A. (2015). Groundwater Prospect in a Typical Precambrian Basement Complex using Karous-Hjelt and Fraser Filtering Techniques. *Journal of Industrial Engineering Research*. 1(4), 40–49.

Oladejo O.P., Sunmonu L.A., Ojoawo A., Adagunodo T.A. and Olafisoye E.R. (2013), Geophysical Investigation for Groundwater Development at Oyo State Housing Estate Ogbomosho, Southwestern Nigeria. *Research Journal of Applied Sciences, Engineering and Technology*, 5(5), 1811–1815.

Ozcep Ferhat and Ozcep Tazegul (2011). Geophysical analysis of the soils for civil (Geotechnical) Engineering and urban planning purposes: some case histories from Turkey. International Journal of the Physical Sciences, 6(5), 1169 – 1195.

Parasnis D.S. (1978). Principle of Applied Geophysics, 3rd Ed. *Chapman and Hall*, New York, USA.

Powrie W., Richards D., Beaven R. (2015). Geotechnical hazards associated with closed municipal solid waste landfill sites. IOP Conf. Series: Earth and Environmental Science, 26, 012002, 1 – 11.

Raji W.O. and Adeoye T.O. (2017). Geophysical mapping of contaminant leachate around a reclaimed open dumpsite. Journal of King Saud University-Science, 29, 348-359.

Sunmonu L.A., Adagunodo T.A., Bayowa O.G. and Erinle A.V. (2016). Geophysical Mapping of the Proposed Osun State Housing Estate, Olupona for Subsurface Competence and Groundwater Potential. *Journal of Basic and Applied Research*. 2(2), 27–47.

Sunmonu L.A., Adagunodo T.A., Olafisoye E.R. and Oladejo O.P. (2012), The Groundwater Potential Evaluation at Industrial Estate Ogbomoso Southwestern Nigeria. *RMZ-Materials and Geoenvironment*, 59(4), 363–390.
Walter Emiedafe (2015). Why buildings collapse in Nigeria. Unite Nigeria, 1. http://unitenigeria.com/why-building-collapse-in-nigeria/
Zohdy A.A. and Maboy D.R. (1974). Application of surface geophysics to groundwater investigation. U.S. Geol. Surv. Book 2 Ch. D1, 304-320.